Beacon Signals: What, Why, How, and Where?

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In ancient times, beacons were hilltop fires or lights that served as warning signals to spread word of invasion, natural disaster, or other emergencies. Today, beacons are primarily radio, ultrasonic, optical, laser, or other types of signals that indicate the proximity or location of a device or its readiness to perform a task. Beacon signals also carry several critical, constantly changing parameters such as power supply information, relative address, location, timestamp, signal strength, available bandwidth resources, temperature, and pressure.

Although transparent to the user community, beacon signals have made wireless systems more intelligent and humanlike. As Table 1 shows, they are an integral part of numerous scientific and commercial applications ranging from mobile networks to search and rescue operations and location tracking systems.

Beacon signals are an integral part of various new applications, including all wireless systems.

CELLULAR NETWORKS

Base stations periodically broadcast one beacon signal per second to identify wireless subscribers in a given area. Mobile devices listen for new beacons, add those they detect to the device's active beacon kernel table, locate the nearest base station, and establish rapport so they can initiate dialogue with the outside world using the base station as a gateway.

Beacon signals carry information such as a cellular network identifier, timestamp, gateway address, paging area ID, and other base station parameters. In the United States, these signals are transmitted via the analog Advanced Mobile Phone System, a first-generation technology, and its second-generation successor, the Cellular Digital Packet Data system. The second-generation Global System for Mobile communications is the cellular standard used throughout Europe and Asia.

Figure 1 illustrates how a cellular network uses beacon signals when a mobile phone user is in a location outside his subscription area—for example, just after getting off an airplane. When the user switches on the handheld device, the beacon signal activates a roaming service, and the user registers and communicates through the closest base station. Implementation of the system typically occurs at three levels: user-level processing at the base stations, user-level processing at the mobile user, and kernel modulation at the mobile user.

WIRELESS LANS

A wireless local-area network links a group of wireless devices controlled by an access point that periodically broadcasts a beacon signal that includes the traffic map, indicating availability of buffered packets for specific LAN nodes. The signal awakens nodes that are in sleep mode because of long idle time and resynchronizes them to receive data from the beacon. Such buffering occurs for all broadcast and multicast messages intended for a group of nodes. Wireless LANs primarily use two different unlicensed industrial, scientific, and medical (ISM) bands, one for analog and mixed signals and another for digital signals.

Because wireless ad hoc networks are formed instantaneously without any fixed infrastructure, they require peer-to-peer mode routing. "Hello" signals function as beacons to inform nearby mobile nodes about existing neighbors. Most ad hoc networking routing protocols—including table-based routing, on-demand distance vector routing, and associativity-based routing—use beacon signals. Ad hoc networks utilize the same two ISM bands as wireless LANs.

GLOBAL POSITIONING SYSTEM

GPS technology originally was designed to accurately navigate weapons from mobile platforms to enemy targets. Operated by the US Department of Defense, 24 satellites orbiting approximately 11,000 miles above the Earth constantly transmit beacon signals containing orbital position information, the current time, and error correction data. An Earth-based GPS receiver triangulates signals from the nearest four satellites to interpret a general position by checking their clock reading, location, and orbit.

Satellite signals can reflect off atmospheric particles as well as buildings, mountains, and other objects before reaching the GPS receiver, thereby leading to calculation errors. Nevertheless,

researchers have extended GPS technology for use in a number of scientific and general-purpose applications such as open-water navigation, search-and-rescue operations, precision agriculture, and geographic surveys.

SEARCH-AND-RESCUE SYSTEMS

Satellite-assisted search-and-rescue systems monitor and respond to emergency beacons generated by individuals located aboard aircraft or ships. For example, Cospas—the abbreviation for Russia's Space System for the Search of Vessels in Distress—provides search-and-rescue satellite-aided tracking by activating 5-Watt RF burst signals of approximately 0.5-second duration every 50 seconds at 406 or 121.5 MHz. The vessel or aircraft in distress transmits information about the country of registration and identification to Cospas-Sarsat low-earth-orbit or geostationary-earth-orbit satellite subsystems, and they forward the data to a designated mission control or national rescue coordination center.

MOBILE ROBOTICS

Researchers have proposed using autonomous mobile robot systems to facilitate distributed coordination and navigation in applications ranging from space exploration to hazardous environment and military operations. In these applications, robots can pick up beacon signals, define the pallet locations, and self-organize to lift the pallets and carry them to their destination. After they deliver a payload to its destination, the robots disperse to continue the operation. When robots use beacon signals, localized information is adequate to provide an autonomous system, and the algorithm does not require them to know the distance from their farthest teammate.

LOCATION TRACKING

The Fraunhofer Institute for Computer Graphics in Rostock, Germany, has developed Mobis, a mobile information system (http://www.rostock.igd.fhg.de/fhg_igd/abteilungen/a3/projects/xyberscout/mobis) that combines electronic beacons and a Palm Pilot to provide self-guided museum tours. As a visitor approaches various locations where electronic beacons are installed throughout the facility such as exhibits, meeting points, or way crossings, the Palm Pilot receives a beacon signal that uses the beacon range and object-sensing device to automatically call up information or directions.

Beacon signals can be either weak, modulated radio signals such as a 2.4-GHz ISM band Bluetooth standard or

Table 1. Applications and characteristics of beacon signals.

Application	Frequency band	Information carried
Cellular networks	824-849 MHz (Advanced Mobile Phone System/Cellular Digital Packet Data system) 1,850-1,910 GHz (Global System for Mobile communications)	Cellular IP network identifier Gateway IP address Paging area ID Timestamp
Wireless LANs	902-928 MHz (industrial, scientific, and medical band for analog and mixed signals) 2.4-2.5 GHz (ISM band for digital signals)	Traffic indication map
Ad hoc networks	902-928 MHz (ISM band for analog and mixed signals) 2.4 to 2.5 GHz (ISM band for digital signals)	Network node identity
Global Positioning System	1575.42 MHz	Timestamped orbital map and astronomical information
Search and rescue	406 and 121.5 MHz	Registration country and ID of vessel or aircraft in distress
Mobile robotics	100 KHz-1 MHz	Position of pallet or payload
Location tracking	300 GHz-810 THz (infrared)	Digitally encoded signal to identify user's location
Aid to the impaired	176 MHz	Digitally coded signal uniquely identifying physical locations

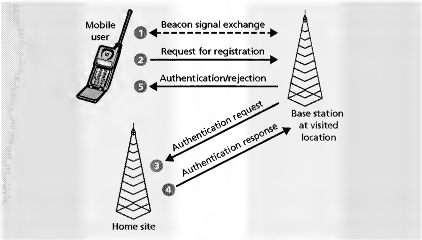

Figure 1. Using a mobile phone outside the subscription area. (1) A mobile phone listens for new beacons and, if it detects one, adds it to the active beacon kernel table. If the device determines that it needs to communicate via a new base station, kernel modulation initiates the handoff process. (2) The mobile phone locates the nearest base station via user-level processing. (3) The visiting base station performs user-level processing and determines who the user is, the user's registered home site for billing purposes, and what kind of access permission the user has. (4) The home site sends an appropriate authentication response to the base station currently serving the user. (5) The base station at the visited location approves or disapproves user access.

pulsed infrared beams. Infrared beacons require a line of sight between the mobile device and beacon to identify the user's orientation, while radio beacons are insensitive to location.

AUDITORY LOCATION FINDER

An auditory location finder is a geographically programmable device that receives digitally coded signals from a set of beacons in a custom-built environment to indicate a user's whereabouts. ALF devices are particularly useful for visually impaired and elderly persons. An ALF device can identify the area, junctions, streets, and pedestrian crossings and provide specific information about stores, post offices, clinics, public telephones, ATM machines, and other services.

To increase accuracy and prevent signal overlaps, ALF systems use strategically placed, short-range beacon signals to identify important locations and features. Constructing simple beacons that use either conventional or solar-powered batteries is relatively inexpensive. The specification for RF transmission of beacons remains the same in different areas, and the ALF device should choose the correct area every time a user activates it.

Beacon signals help synchronize, coordinate, and manage electronic resources using miniscule bandwidth. Researchers continue to improve their functionality by increasing signal coverage while optimizing energy consumption. Beacon signals' imperceptibility and usefulness in minimizing communication delays and interference are spurring exploratory efforts in many domains ranging from the home to outer space. *

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